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Charging for Radioactive Emissions

Abstract. *Radioactive emissions from nuclear power plants can be controlled by using a pollution charge. This is a more effective and simpler procedure than the present method of shutting down plants and leads to a more desirable balance between alternative sources of energy.*

Emissions of radioactive materials in normal operation of nuclear power stations must, according to Nuclear Regulatory Commission (NRC) rules, be kept as low as practicable following the guidelines of the International Committee on Radiological Protection (ICRP). The exact meaning of these words was left to a public hearing lasting 3 years, started by the Atomic Energy Commission and only recently adjudicated by NRC (*1*). This hearing was concerned with the design criteria for power stations using light-water-cooled nuclear reactors (*2*). In the final adjudication, the NCR reaffirmed stringent rules for the design of these plants to reduce radioactive effluents. One basic principle is that a cost-benefit analysis be performed on further reducing the integrated radiation exposure (measured in man-rem, the product of population and radiation dose) to the general public below the stipulated design guides. The NRC proposes a future hearing, but suggests that meanwhile a cost equivalent to $1000 per man-rem be selected as a figure below which it would be deemed worthwhile to install equipment to reduce the dose. This figure of $1000 is very conservative, but we will take it for the purpose of subsequent argument.

On occasion, equipment is defective or unusual operation can occur. Then with continued operation radioactive emissions may temporarily increase above the technical specifications for the power station calculated according to the various rules, including the cost-benefit analysis below. The NRC notes that it would not be appropriate to shut a power station down merely because of a temporary increase of emissions, but the exact mechanism of control is not specified.

It is the purpose of this report to point out that this is a case where a pollution charge should be a very logical and efficient method of control. I do not wish to single out radioactivity as the only case for a pollution charge; pollution charges for sulfur emission control have also been suggested (*3*) for similar reasons. It is important to realize that, like the effects of sulfur emission, the effect of a temporary emission of radioactive material above the technical specification will not be catastrophic (and may even be zero if there is a threshold in the curve of health effect versus dose) so that instantaneous action such as shutdown of the power station is not warranted. Given our present lack of knowledge, it is desirable to be cautious and to encourage prompt correction. As we see in the example below, even assigning a large cost to a dose integrated over population (man-rem) will give a much smaller charge than the effects of some existing power reductions. The question for public policy is, Would it be better to run the nuclear power station with its higher than usual emission, or to forgo the benefits of the electric power generated and shut the station down? Many complex factors will enter into the decision, such as the length of time for which the shutdown will be necessary, the availability of other generating capacity, and so forth. By imposing a pollution charge, this complex question would be put firmly into the hands of the utility company in just the form they are uniquely qualified to deal with—namely, What is the cheapest way to generate electricity?

Therefore, I propose that whenever the emissions from a power station reach a point where action must, under present rules, be taken (I believe that this is when one-half the yearly emission allowed in the technical specification is reached in one quarter) a charge be made in lieu of all other actions, until the ICRP limit of 500 millirems a year is reached. This charge would be calculated on a yearly average to be based on $1000 per man-rem calculated or whatever other sum per man-rem the future NRC public hearing may decide on as appropriate. As noted above, $1000 is a very conservative figure, but a charge based on $1000 per man-rem will usually cost less than shutting a power station down. Using the figures from the recent National Academy of Sciences report on the biological effects of ionizing radiation (*4*), we find that 1 man-rem might (assuming no threshold below which radiation has no effect) cause 10^{-4} cancers; this corresponds therefore to a charge of $10 million per cancer, which is more than society usually spends on cancer-reducing actions (*5*). I would prefer to choose a charge of $100 per man-rem, but even with the higher charge, the examples below show that the pollution charge would be better than power restrictions.

A question might arise about how to calculate the dose effect of the excess emissions. This might arise, in particular, at an existing plant where the effects of such emissions have not been precisely calculated. In such a case the NRC could take an appropriately conservative view, which might then be contested by the power company (or by environmentalists). But all this argument could take place at our leisure, while the power station is still operating. It would clearly not be worth the trouble for a utility company to contest small NRC charges. After an initial flurry of activity, adjudication of charges will not happen too frequently because precedents will be set by the first few cases. At present the NRC asks for prompt reports and action on unusual emissions. The public health problem is calculated on the basis of a dose given all at once, and can only be less if spread out over a long time period. It is only the average over a year or so that counts. Since a utility company would want to reduce the charge it would be expected to take prompt action on its own, and no other immediate action should be necessary.

This might work in a particular case as follows. Under the present system, a 1000-Mwe reactor might be shut down and its contribution to the electrical grid replaced with power from another station that usually utilizes oil. This will be about 40,000 barrels a day. We should take the cost of the last barrels the country buys, presumably imported. This is half a million dollars, which adds this much to our balance of payments deficit. A power reduction to 80 percent of full power costs one-fifth of this—$100,000 a day. To this has to be added a pollution charge for the replacement fuel.

Such power reductions have been ordered at New England power stations, when high site boundary doses (dominated by iodine, with an assumed concentration through the grass-cow-milk-thyroid chain) due to unusual plant releases were calculated. Let us assume the dose goes up to 25 millirem per year. Assuming, in a most unlikely case, that this applies to the whole population of a neighboring town of 20,000 people, the total dose integrated over population would be 500 man-rems per year, or $500,000 a year at $1000 per man-rem. This corresponds roughly to the total societal cost and is much less than $100,000 per day for a power reduction, but it seems quite enough incentive to persuade a plant superintendent to collect a spare part by private jet plane. Although the pollution charge will go into the utility company rate base, it will be only partially passed on to the consumer; there is always some incentive left to a utility company to be financially efficient.

It might be objected that the integrated doses considered are not only smaller than the integrated natural background radiation, they are smaller than the 5 percent variations in this background due to such matters as snow cover on the ground, and therefore a pollution tax would call excessive attention to nuclear power as a radiation source. However, NRC regulatory practices already bring this attention (*2*). My proposal, by allowing power stations to run at a higher power level than is often the present case, would reduce the excessive attention.

It is, I believe, important to consider this payment as a pollution charge, and not a tax or a fine; it is closely related to the problems caused by the pollution but no blame should necessarily be assigned. In principle, it would be desirable that this charge be paid to the people most affected by the pollution. This, in technical matters, is the principle of negative feedback or closing the feedback loop. Various articles have been written on the application of this principle to social affairs (*6*).

One possibility would be to transfer the payment, less the cost of collection, to the township in which the power station is located to reduce its taxes; another, to a local cancer hospital.

In several recent cases of excess emissions of radioactivity from nuclear power stations, power reductions have been ordered. The power has been made up by oil- or coal-fired power stations, and this has caused either an increase in balance of payment problems, or an increase in air pollution, with its own health cost, or a little of both. It is my belief that any self-adjusting system based on a pollution charge should allow these power stations to operate at full capacity, and thereby prevent wastage of scarce human resources and also reduce the world's total pollution problems.

Since I envisage this replacing an appreciable fraction of NRC regulatory activities and rules with the certainty that power companies will, literally, pay for any mistake, there should be no problem in administering a charge of this sort. Administering the design criteria can be left, to a greater extent than is presently planned, to the utility company.

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Composition of Atmospheric Particulate Matter from the Eruption of Heimaey, Iceland

Abstract. *The chemical composition of atmospheric particulate matter and rock samples collected on the island of Heimaey after the January 1973 eruption indicates that volcanic activity is a possible source of global significance for particulate material containing elements such as Br, Se, Sb, and Zn. Atmospheric aerosols from such remote areas as the North Atlantic Ocean and the South Pole are found to be highly enriched in these elements.*

Studies of the composition of atmospheric particulate matter in remote areas such as the North Atlantic Ocean and the South Pole indicate that atmospheric aerosols from such locations are substantially enriched in certain elements (Se, Sb, Pb, Br, Zn, and Cu) (*1, 2*). The relatively high volatility of these elements and many of their compounds suggests that a high-temperature dispersal process may be responsible for injecting these elements into the atmosphere. Although the North Atlantic Ocean and the South Pole are widely separated, the fact that the enrichment factors are similar in these two regions suggests that the sources for these elements are natural and widely dispersed (*1*).

Volcanoes have long been recognized as a major source of atmospheric aerosols and could conceivably be responsible for at least part of the observed elemental enrichments. On a global scale, it is estimated that volcanoes produce between 25×10^6 and 150×10^6 metric tons of fine particles (radius, < 20 μm) per year (*3*). This represents between 1 and 20 percent of the total estimated natural aerosol production rate (*3*). The importance of volcanoes as a source of atmospheric particulate material in the lower stratosphere and its subsequent global transport has been discussed elsewhere (*4*). It has been suggested that trace elements of high volatility could easily be transported out of the magma

Table 1. Elemental composition of Heimaey aerosols, lava-ash samples, and fumarole deposits. Abbreviation: ppm, parts per million.

Element	Aerosols		Lava-ash	Fumarole deposits
	Site A (ng/m³)	Site B (ng/m³)		
Cl	56,000 ± 8,000	14,000 ± 2,000	540 ± 190 ppm	4.4 ± 3.8%
Na	34,000 ± 5,000	9,500 ± 1,400	3.9 ± 0.7%	2.7 ± 1.3%
Fe		2,300 ± 700	9.8 ± 0.5%	6.7 ± 4.6%
Ca	2,200 ± 400	1,800 ± 300	8.4 ± 0.7%	5.9 ± 2.6%
Al	2,000 ± 300	1,900 ± 300	11.0 ± 1.3%	8.7 ± 3.3%
Br	310 ± 45	570 ± 85	~ 5 ppm	950 ± 1,060 ppm
Zn		85 ± 12	491 ± 100 ppm	200 ± 68 ppm
Mn		79 ± 12	1,990 ± 60 ppm	1,200 ± 770 ppm
V		3.3 ± 1.4	270 ± 60 ppm	210 ± 170 ppm
Se	7.6 ± 2.3	25 ± 4	1.0 ± 0.30 ppm	265 ± 260 ppm
Co		1.9 ± 0.6	33.5 ± 1.5 ppm	23 ± 18 ppm
Sb	0.47 ± 0.14	0.53 ± 0.08	0.60 ± 0.30 ppm	0.93 ± 0.76 ppm
Sc	0.47 ± 0.14	0.41 ± 0.06	19.2 ± 4.7 ppm	17 ± 9 ppm
La		0.30 ± 0.09	25.9 ± 2.0 ppm	13 ± 9 ppm
Hf	0.17 ± 0.05	0.14 ± 0.02	5.9 ± 0.6 ppm	0.79 ± 0.04 ppm
Th	0.066 ± 0.013	0.058 ± 0.009	2.2 ± 0.1 ppm	1.2 ± 0.8 ppm
Eu	0.08 ± 0.04	0.025 ± 0.004	2.9 ± 0.4 ppm	0.28 ± 0.05 ppm